NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PERFORMANCE OF A THREE-BLADE HAMILTON STANDARD NO. 6507A-2

PROPELLER ON A REPUBLIC P-47D AIRPLANE

By John J. Gardner

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

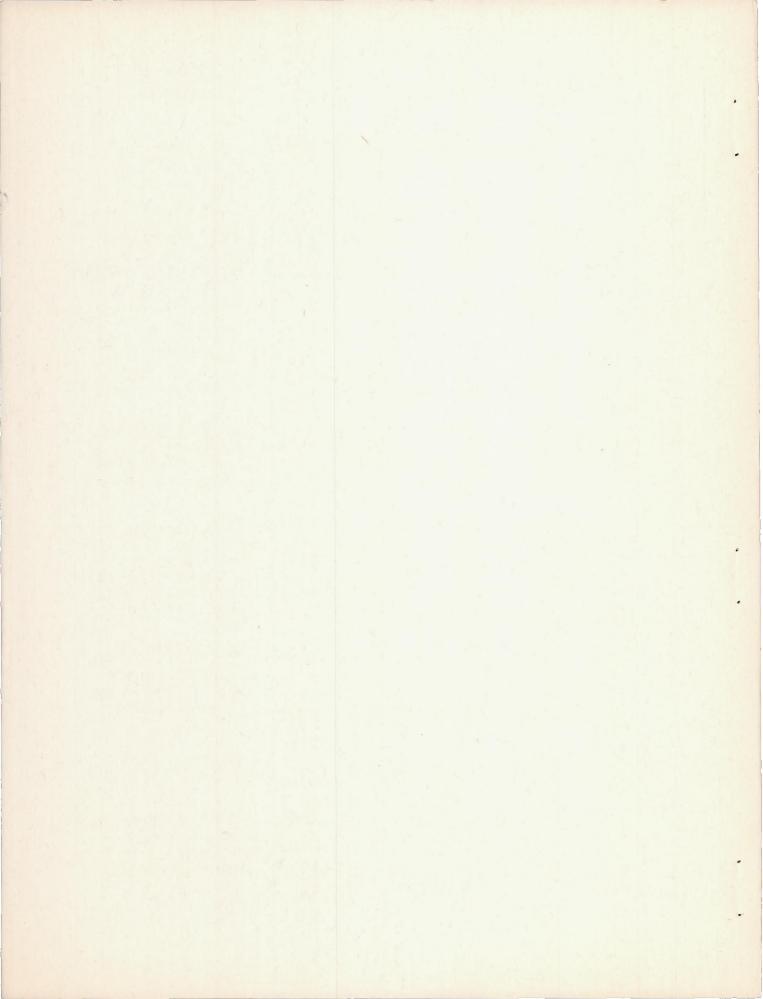
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

EFFECT OF BLADE LOADING ON THE CLIMB AND HIGH-SPEED

PERFORMANCE OF A THREE-BLADE HAMILTON STANDARD NO. 6507A-2

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SUMMARY

As part of a general propeller flight test program at Langley Laboratory, climb and high-speed tests of a Hamilton Standard No. 6507A-2 three-blade propeller have been made to determine the effect of blade loading on propeller efficiency.

The normal and military power climb efficiencies were found to be about equal at altitudes below 16,000 feet. At higher altitudes, the efficiency for the military power condition was 1 to 2 percent lower. At an airplane Mach number of 0.7 a gain of 8 percent in efficiency was obtained with an increase in the power coefficient per blade from 0.06 to 0.09.

Tests at reduced engine speed indicated that, for an advance-diameter ratio of 2.5 and a power coefficient per blade of 0.08, an increase in efficiency of the order of 7 percent was obtained by a reduction in propellertip Mach number from approximately 1.16 to 1.06.

INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, flight tests of a Hamilton Standard No. 6507A-2 three-blade propeller have been made on a P-47D airplane to determine the effect of blade loading on propeller efficiency.

Climbs were made at normal and military power at an indicated airspeed of 165 miles per hour. Other tests were run at 2700 engine rpm at a constant power coefficient per blade of approximately 0.06 and at the additional values of 0.08 and 0.09 through an airplane Mach number range of 0.3 to 0.725. Data were also obtained at a reduced engine rpm of 2520 at constant power coefficients per blade of 0.08 and 0.10 over a similar airplane Mach number range.

SYMBOLS

V	true airspeed
n	propeller rotational speed, revolutions per second
D	propeller diameter
J	advance ratio (V/nD)
β	section blade angle at 0.75 R
θ	blade angle at any section
R	propeller tip radius
r	propeller-section radius
x	r/R
Ъ	blade-section chord
h	blade-section maximum thickness
rs	radial distance from thrust axis to survey point
xs	r _s /R
CT	propeller thrust coefficient
CP	propeller power coefficient
η	propeller efficiency
σ	ratio of density of free air to density of air at sea level

M	airplane	Mach	numbe	r
Mt	propeller	-tip	Mach	number

Mx propeller-section Mach number

PROPELLER AND TEST EQUIPMENT

General specifications of propeller and power plane are as follows:

Number of blades Blade design	0.6507A-2 0.4 10 inches
Normal power rating: Engine speed, rpm Manifold pressure, inches of mercury Brake horsepower Airplane critical altitude (climb), feet (approx.)	1625
Military power rating: Engine speed, rpm Manifold pressure, inches of mercury Brake horsepower Airplane critical altitude (climb), feet (approx.)	2000

Blade-form curves of the test propeller are presented in figure 1. In figure 2 is shown the test propeller and survey rake installed on a Republic P-47D airplane. The measurement of propeller thrust was made by the slipstream-survey method. The test equipment, test procedures, and method of reduction of data are described in reference 1.

RESULTS AND DISCUSSION

Climb tests. - The data of the normal and military power climb tests are presented in table I. In figures 3

and 4 plots of these data indicate the variation of advance-diameter ratio, power and thrust coefficients, efficiency, airplane and tip Mach numbers with density altitude.

4

From the efficiency plots of figures 3 and 4 it will be observed that there is less than I percent difference in efficiency between the normal and military power climb conditions at altitudes below approximately 16,000 feet. At higher altitudes the efficiency for the military power climb condition is 1 to 2 percent lower than that for the normal power condition. Though the efficiency difference between the normal and military power climb condition at the lower altitude is small, comparing these climb efficiencies with the climb efficiencies reported in unpublished data would seem to indicate a consistent effect of power loading on n. This is shown in figure 5 for an advance-diameter ratio of 1.0. This low value of advancediameter ratio was chosen to minimize the effects of compressibility that would occur at higher advance-diameter ratios and, in particular, the unequal effects that would result from the different tip speeds obtained in normal and military power climb tests.

A series of thrust curves for the military power climb tests is presented in figure 6. From these curves it will be noted that compressibility begins to affect noticeably the thrust distribution at a value of x_s^2 of 0.90 on the more highly loaded right side of the propeller at a tip Mach number of approximately 0.95 (run 5-8, fig. 6(d)). This effect on the thrust distribution progresses inboard as far as 0.7 x_s^2 as the tip Mach number is increased but apparently its effect on efficiency is small as noted in figure 4. Lateral shift in the surveys with respect to the survey rake is attributed to a change in sideslip of the airplane as discussed in reference 2.

High-speed tests. - 2700 rpm - The results of the high-speed, 2700 rpm tests are presented in table II. Curves of propeller efficiency as a function of airplane Mach number as measured in these tests are shown in figure 7.

It will be observed from these curves that in the low-speed range the efficiency gradually drops off as the power coefficient per blade is increased from 0.06 to 0.09. This is in agreement with the variation of

efficiency with blade loading observed in the climb tests. Of particular interest is the high-speed portion of these curves. At an airplane Mach number of 0.7 an increase in the power coefficient per blade from 0.06 to 0.08 results in a 6-percent efficiency gain. A further increase in power coefficient per blade to 0.09 results in an additional efficiency increase of approximately 2 percent.

A brief analysis of the high-speed data for the several blade loading conditions reveals that, at the higher loadings, the outboard sections are taking an increased portion of the total load. This is shown in figure 8. The thrust grading curves for the runs indicated in this figure have been multiplied by the factor J/Cp to adjust the survey thrust values for differences in power and small differences in speed. Included in this figure are curves of propeller section Mach numbers plotted against x_s^2 with the assumption that $x^2 = x_s^2$. This assumption is considered sufficiently accurate to permit a comparison of the section Mach number ranges for the several runs shown. The increase in efficiency at high speeds obtained in going to high blade loadings would indicate that the outboard sections are assuming the increased load more efficiently. This in turn would indicate at the higher powers that these sections are operating at more favorable values of lift-drag ratio.

Thrust grading curves obtained in tests at a power coefficient per blade of 0.08 are presented in figure 9. These curves show the progressive inboard shift of the region where losses in thrust occur as the tip Mach number changes from 1.00 to 1.15.

2520 rpm. - The results of the constant power coefficient tests at reduced rpm are shown in table III. Efficiency curves for the two test conditions of power coefficients per blade of 0.08 and 0.10 are presented in figure 10. These curves indicate a trend in efficiency with changing power coefficient similar to that found in the 2700 rpm tests. At the high-speed condition, M = 0.7, an efficiency increase of approximately 2 percent is obtained with an increase in power coefficient per blade from 0.08 to 0.10.

A comparison of the 2520 rpm and 2700 rpm tests results for a power coefficient per blade of 0.08 is presented in figure 11. It will be seen from this figure

that a reduction in tip Mach number from 1.16 to 0.90 results in higher efficiency. At an advance-diameter ratio of 2.5 for this power condition, an increase of approximately 7 percent in efficiency is obtained by a reduction in tip Mach number from 1.16 to 1.06. This value is in good agreement with the results obtained in reference 1.

CONCLUSIONS

Flight tests of the Hamilton Standard No. 6507A-2 three-blade propeller on a Republic P-47D airplane equipped withan R-2800-59 engine indicated the following conclusions:

- 1. The propeller efficiency for the normal and military power climb conditions is approximately the same at altitudes below 16,000 feet. At 25,000 feet, military power climb efficiency is approximately 2 percent less than normal power climb efficiency.
- 2. At an airplane Mach number of 0.7 and 2700 engine rpm, increasing the power coefficient per blade from 0.06 to 0.09 results in an increase in efficiency of the order of 8 percent.
- 3. At an advance-diameter ratio of 2.5 and power coefficient per blade of 0.08, a reduction in propeller tip Mach number from approximately 1.16 to 1.06 increases the propeller efficiency by approximately 7 percent.

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REFERENCE

1. Vogeley, A. W.: Climb and High-Speed Tests of a Curtiss No. 714-1C2-12 Four-Blade Propeller on the Republic P-47C Airplane. NACA ACR No. 14107, 1944.

TABLE I

FLIGHT DATA OBTAINED FROM NORMAL AND MILITARY

CLIMB TESTS OF HAMILTON STANDARD NO. 6507A-2 THREE-BLADE

PROPELLER UN P-47D AIRPLANE

Fig.	Run	J	C _P	$C_{\mathbf{T}}$	7	n (rps)	M	Mt	100
3	3-1	.920	.107	.0910	.778	21.25	. 228	.811	.905
3	3-2	.957	.115	.0911	.758	21.30	. 239	.819	.864
3	3-3	.957	.121	.0991	.783	21.50	.242	.830	.815
3	3-4	.978	.128	.1023	.779	21.35	.247	.830	.794
3	3-5	.990	.135	.1058	.784	21.50	.255	.842	.747
3	3-6	1.029	.142	.1079	.781	21.40	. 263	.844	.711
3	3-7	1.059	.151	.1129	.794	21.35	.271	.848	.674
	38	1.076	.156	.1143	.789	21.50	.279	.860	.642
3	3-9	1.096	.164	.1188	.795	21.45	.285	.866	.612
3	3-10	1.128	.171	.1208	.795	21.32	. 294	.869	. 585
3	3-11	1.154	.182	.1268	.803	21.35	.302	.876	. 557
3	3-12	1.201	.189	.1264	.801	21.25	.315	.883	. 533
3	3-13	1.217	.198	.1295	.797	21.30	.322	.891	. 508
3	3-14	1.239	.205	.1322	.799	21.30	.330	.901	.490
3	3-15	1.251	. 209	.1345	.807	21.50	.339	.917	.471
3	3-16	1.277	.218	.1347	.789	21.45	.348	.924	.453
3	3-17	1.287	. 226	.1418	.808	21.45	.352	.927	.432
3	3-18	1.331	. 232	.1394	.800	21.50	.367	.939	.414
3	3-19	1.355	.241	.1430	.802	21.42	.374	.944	.401
3	3-20	1.379	. 249	.1449	.801	21.45	.383	.958	.387
3	3-21	1.399	. 256	.1456	.798	21.50	.391	.961	.373
3	3-22	1.420	.263	.1482	.800	21.50	.399	.969	.361
4	5-1	.974	.160	.1291	.786	22.35	. 257	.869	.748
4, 6(a)	5-2	1.019	.172	.1311	.777	22.45	.273	.884	.687
4	5-3	1.061	.188	.1392	.786	22.40	.285	.892	.629
4, 6(b)	5-4	1.128	. 200	.1402	.791	22.50	.308	.912	.581
4	5-5	1.156	.215	.1483	.797	22.40	.514	.911	.535
4, 6(c)	5-6	1.187	. 230	.1517	.783	22.47	. 326	.924	.494
4	5-7	1.235	. 239	.1525	.788	22.52	.343	.936	.463
4, 6(d)	5-8	1.273	. 250	.1566	.798	22.50	.356	.948	.439
4, 6(e)	5–9	1.297	. 262	.1580	.782	22.50	.366	.959	.417
4, 6(f)	5-10	1.322	.270	.1595	.781	22.50	.376	.968	.399
4	12-1	.880	.125	.1102	.776	22.30	. 236	.874	.943
4	12-2	.916	.142	.1192	.769	22.32	. 246	.879	.853
4	12-3	.979	.150	.1202	.785	22.23	. 260	.874	.764
4	12-4	1.025	.167	.1271	.780	22.18	. 272	.876	.704
4	12-5	1.049	.182	.1347	.776	22.19	.281	.888	.651
4	12-6	1.102	.193	.1389	.793	22.26	. 296	.894	. 597
4	12-7	1.139	.206	.1401	.775	22.27	.308	.903	The state of the s
4	12-8	1.175	. 225	.1510	.789	22.28	.319	.909	. 554
4	12-9	1.213	.231	.1514	.795	22.32			.512
4	12-10	1.246	.248	.1565	.786	22.31	.334	.927	.487
4	12-11	1.270	.257	.1606	.794	22.26		.936	.458
4	12-12	1.317	.261	.1562	.788	22.35	.354	.944	.432
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TABLE II

FLIGHT DATA OBTAINED FROM HIGH-SPEED, 2700 ENGINE

RPM TESTS OF HAMILTON STANDARD NO. 6507A-2 THREE-BLADE

PROPELLER ON P-47D AIRPLANE

Fig.	Run	J	CP	CT	7	n (rps)	M	Mt	0
7, 8	3-23	2.622	.182	.0434	.625	22.35	.708	1.105	.645
7	3-24	2.486	.173	.0462	.664	22.23	.669	1.079	.642
7	3-25	2.187	.180	.0638	.775	22.50	. 596	1.043	.623
7	3-26	1.943	.185	.0775	.814	22.30	. 524	.996	.621
7	3-27	1.674	.183	.0904	.827	22.45	.454	.967	.618
7	3-28	1.398	.181	.1050	.811	22.70	.384	.943	.618
7	3-29	1.152	.184	.1215	.761	22.50	.314	.910	.620
7	3-30	.884	.181	.1441	.704	22.50	.240	.886	.623
7, 8, 11	5-11	2.499	. 227	.0607	.668	22.42	.704	1.130	.467
7, 11	5-12	2.252	.243	.0820	.760	22.37	.631	1.084	. 448
7, 11	5-13	2.075	.244	.0962	.818	22.37	. 588	1.066	.443
7, 11	5-14	1.850	. 251	.1119	.825	22.39	.516	1.016	.428
7, 11	5-15	1.617	.250	.1289	.834	22.38	.451	.986	.431
7, 11	5-16	1.405	. 253	.1476	.820	22.40	.392	.961	.432
7, 11	5-17	1.086	.250	.1711	.743	22.34	.303	.927	.432
7, 8	13-16	2.443	.265	.0742	.684	22.53	.719	1.171	.405
7	13-17	2.133	.271	.0964	.759	22.50	.628	1.117	.393
7	13-18	1.892	.270	.1152	.807	22.37	. 553	1.071	.395
7	13-19	1.661	.276	.1315	.791	22.53	.489	1.046	.393
9(a), 11	13-25	1.488	. 244	.1333	.813	22.49	.430	1.003	.450
9(b), 11	13-24	1.694	. 246	.1188	.819	22.52	.490	1.032	.450
, 9(c), 11	13-23	1.990	. 237	.0955	.802	22.50	. 573	1.071	.460
9(d), 11	13-22	2.225	. 238	.0805	.753	22.41	. 637	1.103	. 469
9(e), 11	13-21	2.403	. 233	.0680	.701	22.50	. 690	1.136	.477
9(f), 11	13-20	2.484	. 233	.0650	.693	22.50	.713	1.149	. 477
7	17-14	2.429	.272	.0826	.738	22.29	.687	1.122	.398
7	17-15	2.224	.284	.0976	.764	22.50	.634	1.098	.382
7	17-16	1.937	.282	.1203	.826	22.27	.552	1.052	.382
7	17-17	1.696	. 280	.1318	.798	22.40	. 485	1.021	.382
7, 11	17-18	2.079	. 257	.0992	.802	22.45	.579	1.048	.434
7, 11	17-19	1.845	. 256	.1154	.832	22.40	.517	1.020	.431
7, 11	17-20	1.596	. 253	.1298	.819	22.31	. 446	.985	.436
7, 11	17-21	1.383	. 254	.1469	.800	22.40	. 388	.964	.434
7	17-22	2.545	.189	.0488	.657	22.11	.681	1.081	.624
7	17-23	1.973	.191	.0818	.845	22.26	. 527	.991	.619
7	17-24	2.269	.191	.0630	.748	22.37	.607	1.037	.618
7	17-25	1.692	.192	.0948	.835	22.24	. 454	.957	.612
7	17-26	1.422	.187	.1075	.818	22.31	.381	.925	.628
7	17-27	1.174	.190	.1294	.799	22.30	.315	.901	.613
7	17-28	.892	.188	.1492	.708	22.24	. 239	.876	.621

TABLE III

FLIGHT DATA OBTAINED FROM HIGH-SPEED; 2520 ENGINE

RPM TESTS OF HAMILTON STANDARD NO. 6507A-2 THREE-BLADE

PROPELLER ON P-47D AIRPLANE

Fig.	Run	J	C _P	$C_{\mathbf{T}}$	7	n (rps)	М	Mt	0
10, 11	18-1	2.435	.230	.0703	.744	21.26	.651	1.063	.440
10, 11	18-2	2.664	. 229	.0575	.669	21.28	.709	1.095	.452
10, 11	18-3	2.571	. 243	.0676	.715	21.11	.681	1.075	.438
10, 11	18-4	2.182	. 246	.0907	.804	21.01	.576	1.010	.436
10, 11	18-5	1.865	. 243	.1115	.856	21.11	.495	.970	.436
10, 11	18-6	1.633	. 243	.1264	.849	21.14	. 434	.942	. 438
10, 11	18-7	1.304	. 240	.1499	.815	21.14	.346	.904	.440
10	18-8	2.686	. 296	.0773	.701	21.15	.709	1.092	.452
10	18-9	2.572	.303	.0888	.754	21.07	.680	1.074	. 439
10	18-10	2.425	. 299	.0970	.787	21.06	.641	1.049	.444
10	18-11	2.170	.304	.1155	.824	21.05	.574	1.010	. 439
10	18-12	1.875	.303	.1363	.844	21.10	.498	.971	.438
10	18-13	1.627	.300	.1522	.825	21.14	.433	.941	.438
10	18-14	1.311	. 299	.1812	.795	21.11	.348	.904	.439
10, 11	19-1	2.698	. 235	.0601	.690	21.17	.709	1.089	.447
10, 11	19-2	2.633	. 247	.0677	.722	21.10	.696	1.084	.431
10, 11	19-3	2.405	. 239	.0778	.783	20.99	.630	1.036	.441
10, 11	19-4	2.121	.242	.0930	.815	20.97	. 555	.991	.442
10, 11	19-5	1.860	.246	.1111	.840	21.28	.495	.972	.428
10, 11	19-6	1.619	.240	.1242	.838	21.30	.431	.940	. 432
10, 11	19-7	1.285	.245	.1564	.820	21.08	.339	.898	.431
10	19-8	2.736	. 297	.0769	.708	21.19	.720	1.096	. 434
10	19-9	2.558	.292	.0872	.764	20.97	.664	1.052	.451
10	19-10	2.380	. 289	.0974	.802	20.97	.618	1.023	.461
10	19-11	1.851	.302	.1375	.843	21.27	.490	.966	.433
10	19-12	2.194	.310	.1176	.832	20.97	. 575	1.004	.431
10	19-13	1.621	.306	.1557	.825	21.02	.426	.929	.430
10	19–14	1.306	.306	.1829	.781	20.90	.342	.891	.430

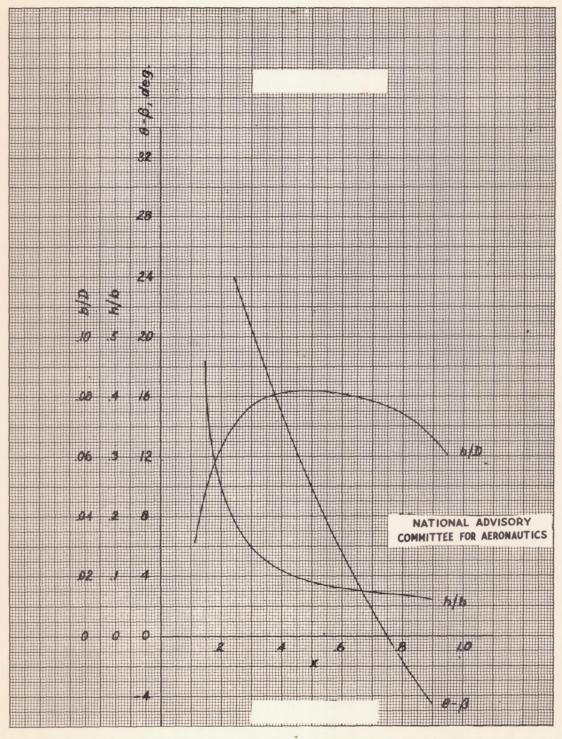


Figure 1.- Blade-form curves of Hamilton Standard No. 6507A-2 threeblade propeller.



Figure 2.- Hamilton Standard No. 6507A-2 three-blade propeller on Republic P-47D airplane.

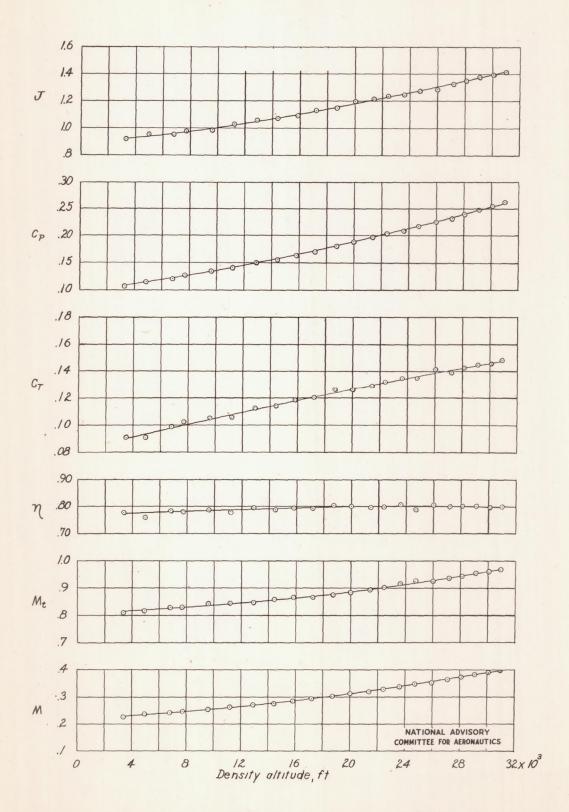


Figure 3.- Normal power climb tests of the three-blade Hamilton Standard 6507A-2 propeller on the P-47D airplane at an indicated airspeed of 165 miles per hour.

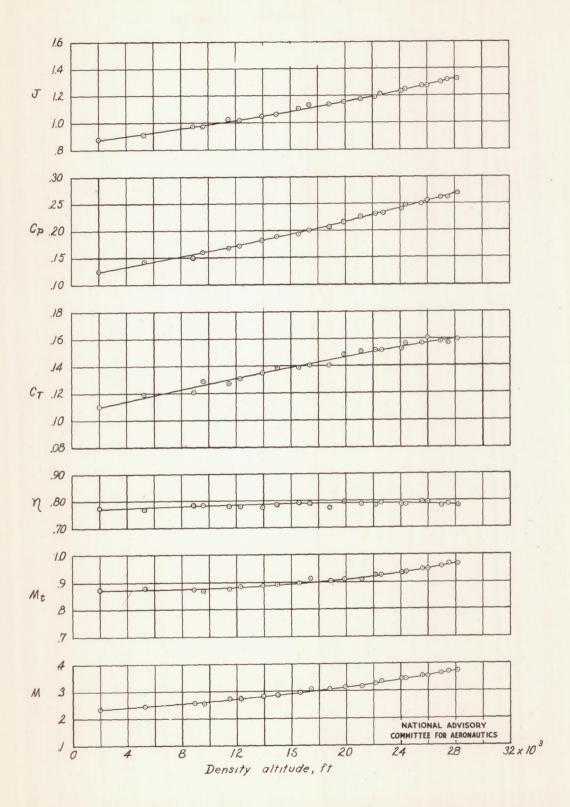


Figure 4.- Military power climb tests of the three-blade Hamilton Standard 6507A-2 propeller on the P-47D airplane at an indicated airspeed of 165 miles per hour.

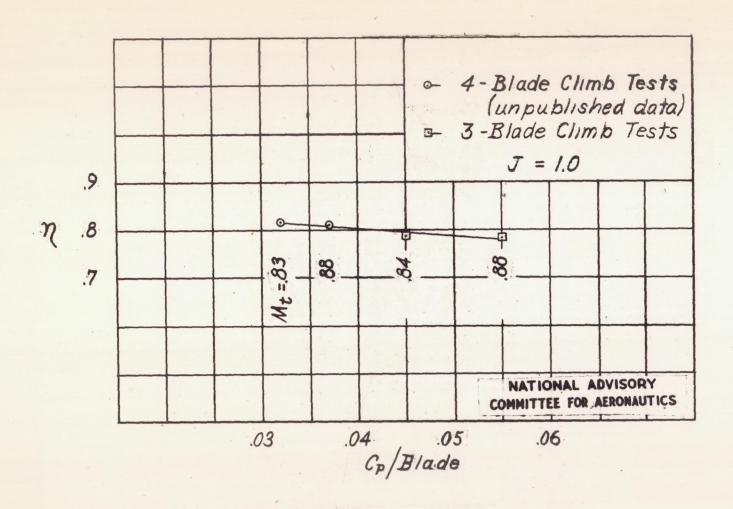


Figure 5.- Effect of blade loading on climb efficiency. Three- and four-blade tests of Hamilton Standard No. 6507A-2 propeller.

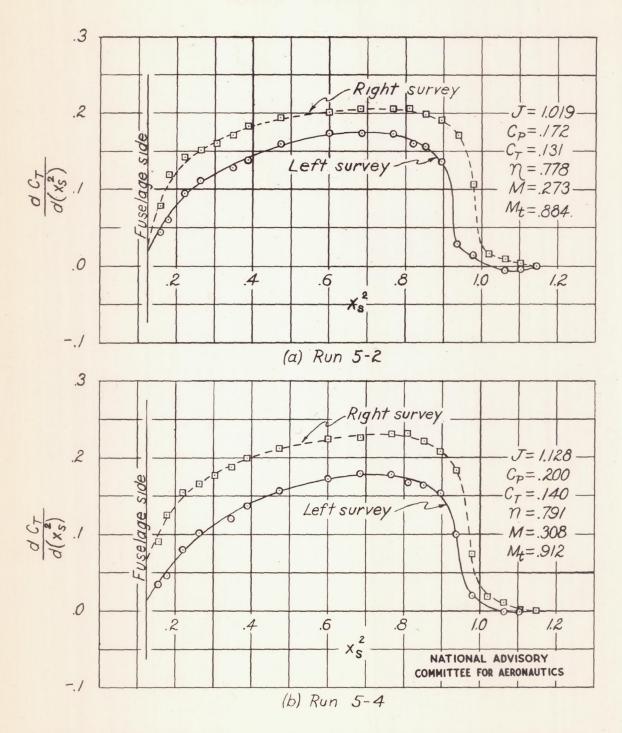


Figure 6.- Thrust grading curves for climb at military power. Indicated airspeed, 165 miles per hour. Hamilton Standard No. 6507A-2 three-blade propeller on the Republic P-47D airplane.

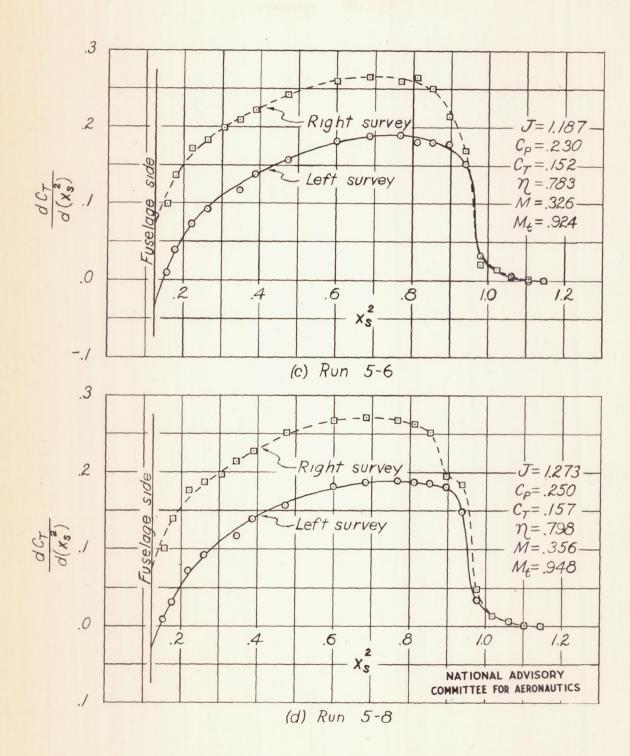


Figure 6. - Continued.

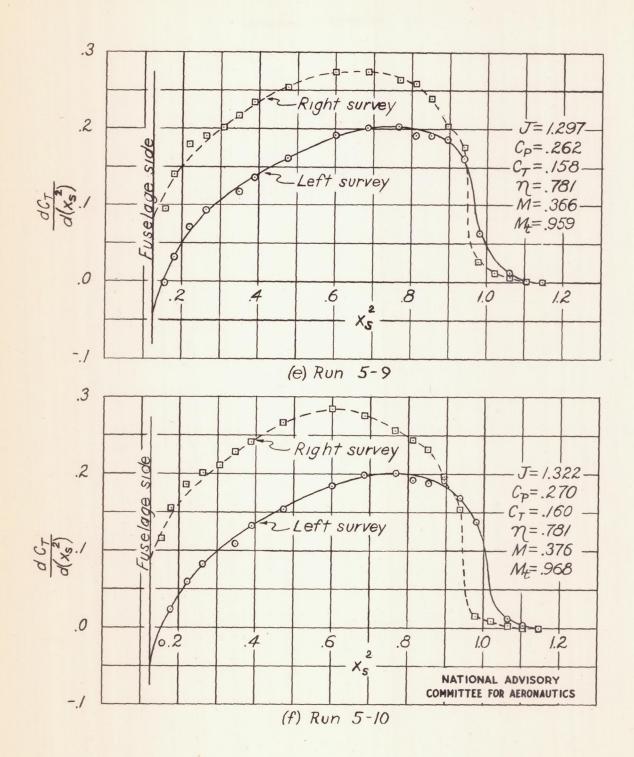


Figure 6. - Concluded.

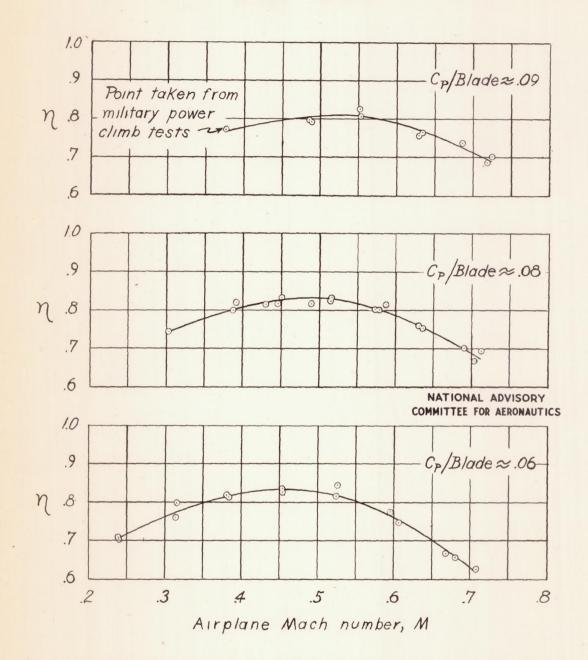


Figure 7.- Effect of blade loading on propeller efficiency over airplane Mach number range. 2700 engine r.p.m. Hamilton Standard No. 6507A-2 three-blade propeller on P-47D airplane.

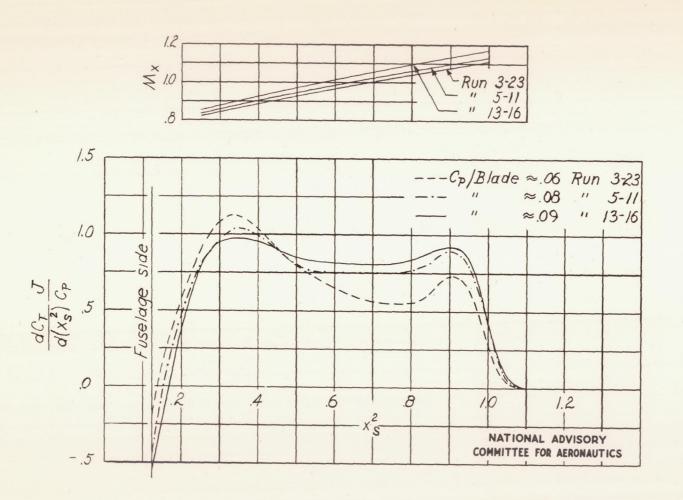


Figure 8.- Comparative thrust-grading curves for several blade loading conditions. Advance-diameter ratio approximately 2.5, airplane Mach number approximately 0.7. Hamilton Standard No. 6507A-2 three-blade propeller on P-47D airplane.

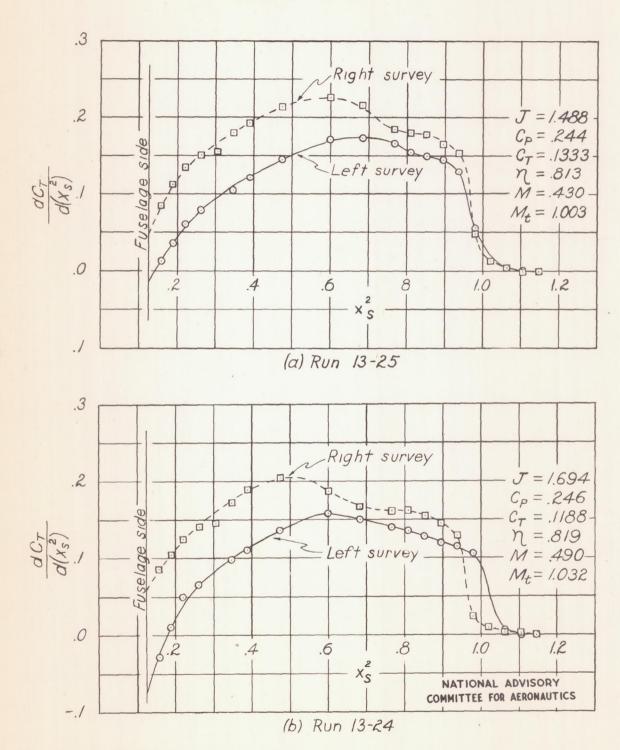


Figure 9.- Thrust grading curves for tests at constant power coefficient per blade of 0.08 over airplane Mach number range. Hamilton Standard No. 6507A-2 three-blade propeller on P-47D airplane.

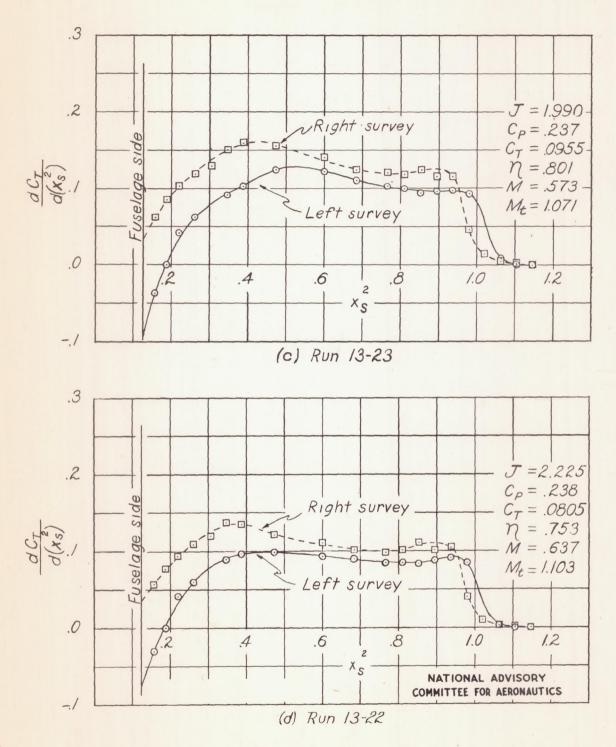


Figure 9. - Continued.

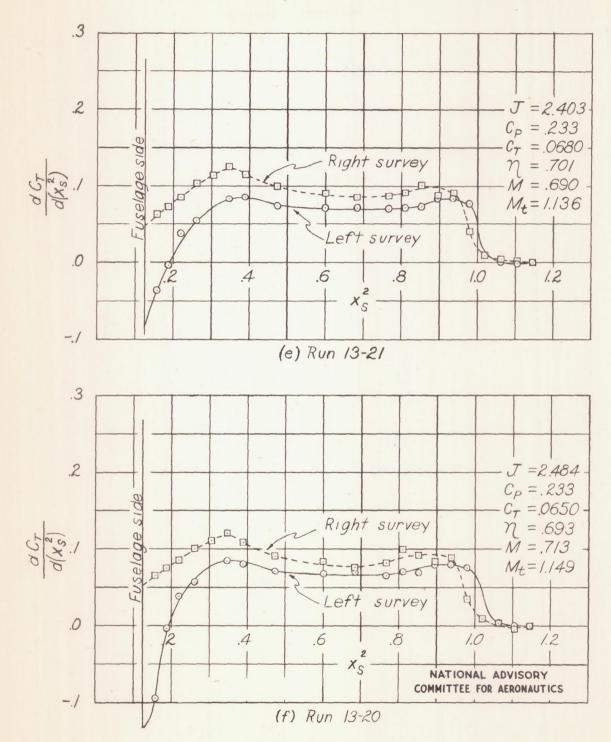
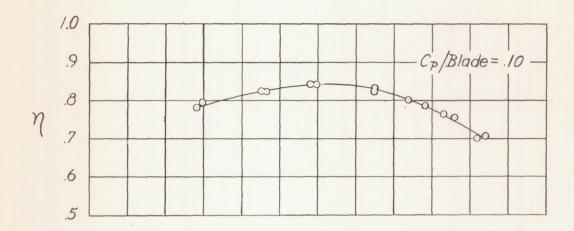


Figure 9. - Concluded.



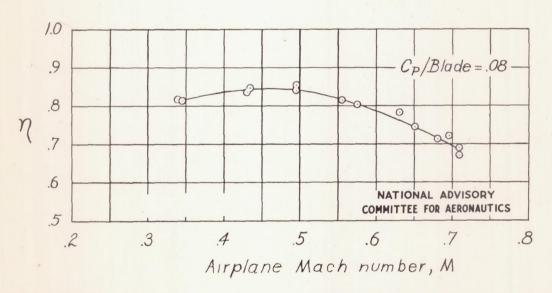


Figure 10.- Effect of blade loading on propeller efficiency over airplane Mach number range. 2520 engine rpm. Hamilton Standard No. 6507A-2 three-blade propeller on P-47D airplane.

Figure 11.- Effect of compressibility on propeller efficiency for constant power coefficient. Power coefficient per blade approximately 0.08. Hamilton Standard No. 6507A-2 three-blade propeller on a P-47D airplane.